Herschel observations of molecular emission lines in low- and intermediate-mass evolved stars

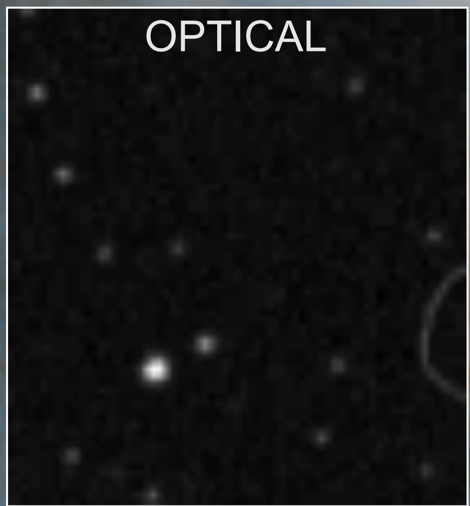
Pedro García-Lario[1], Jesús Ramos-Medina[2], Carmen Sánchez-Contreras[2], Joao da Silva Santos[2,3]

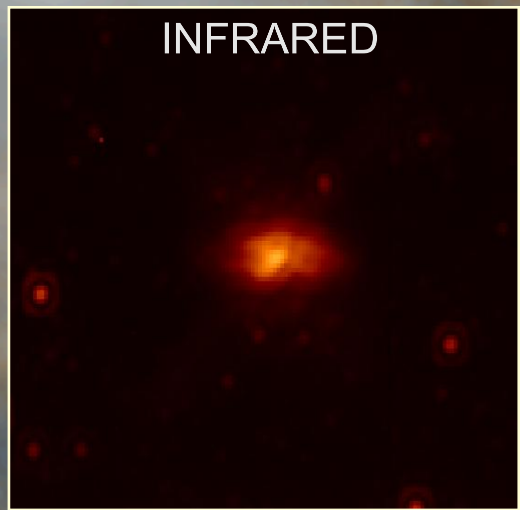
[1] ESAC / ESA, Madrid, Spain
[2] INTA-CSIC, Centro de Astrobiología, Madrid, Spain
[3] Universidade do Porto, Portugal

Background

- Low- and intermediate-mass evolved stars (1-8 $M_\odot$) in the transition from the late AGB (Asymptotic Giant Branch) phase to the PN (planetary nebula) stage are among the brightest sources in the sky in the infrared, before they become white dwarfs

- Strong mass loss (10^{-4} – 10^{-5} $M_\odot$/yr) as a consequence of periodic thermal pulses at the end of the AGB generates thick circumstellar shells of gas and dust, which sometimes completely obscure the light coming from the central star in the optical, associated to high velocity outflows that can help developing bipolar/complex morphologies

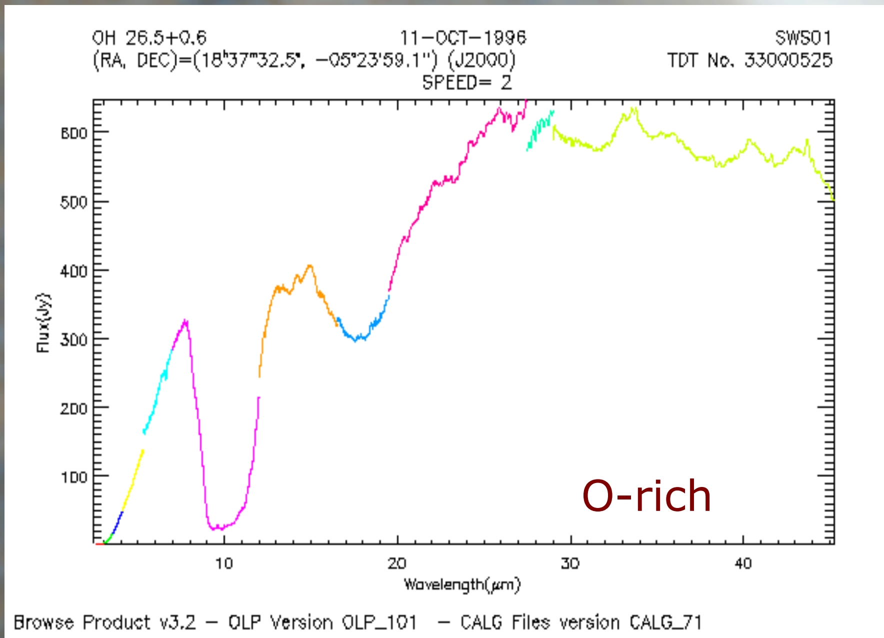


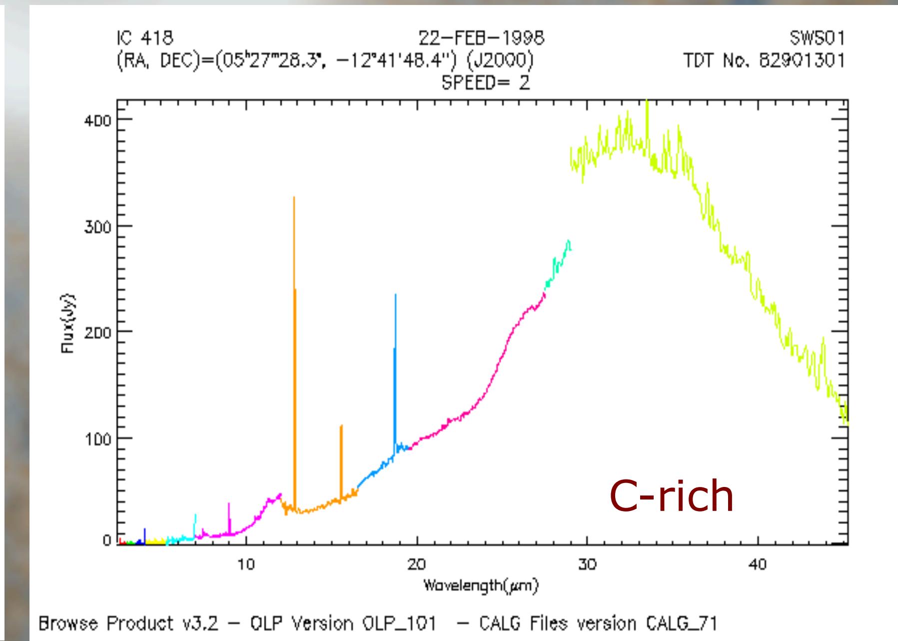


Evolved stars and astrochemistry

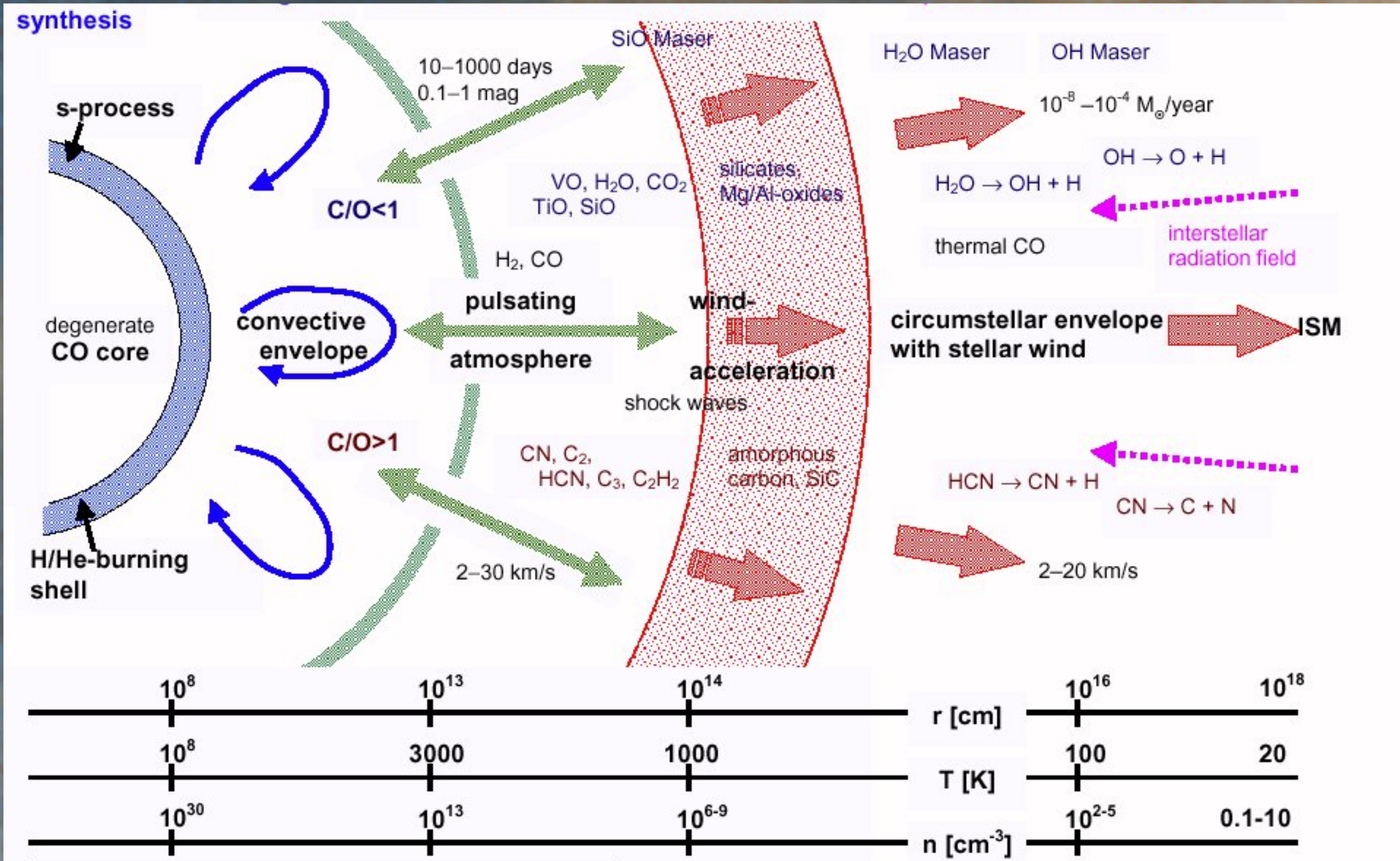
- Chemical composition of the shell reflects the nucleosynthesis experienced by the central star. Of major importance here is the C/O ratio, as it determines the formation of totally different chemical species and dust grains (C-rich vs. O-rich chemistry)

- Previously studied with ISO/SWS, Spitzer/IRS and AKARI/IRC , mainly at mid-infrared wavelengths, resulting in significant progress on the understanding of how molecules form and evolve to complex structures (e.g. PAHs, fullerenes) and the detection of many new dust features (crystalline silicates, HACs, ..)





Schematic view of an AGB star



What can we learn with Herschel?

- Extend the analysis to far-infrared wavelengths at higher resolution and more extended coverage in wavelength than other facilities in the past (mainly ISO/LWS: 43-197μm), providing complementary information to what can be obtained from ground-based sub-mm facilities (IRAM, JCMT, .. ALMA more recently).

- All instruments onboard Herschel can contribute: PACS (57-210μm, with R=1000-5000), SPIRE (194-672μm, with R=40-1000) and HIFI (157-212μm, 240-625μm with R as high as 10^7!)
  - Thermal continuum emission of the cool dust component – mass loss history
  - Important molecular lines (CO, OH, H_2O,..) – specially those formed at the warm inner layers of the shell
  - Solid state dust spectral features – extension of ISO/Spitzer findings
  - Kinematics, from HIFI spectroscopy – high velocity outflows

THROES: A caTalogue of HeRschel Observations of Evolved Stars

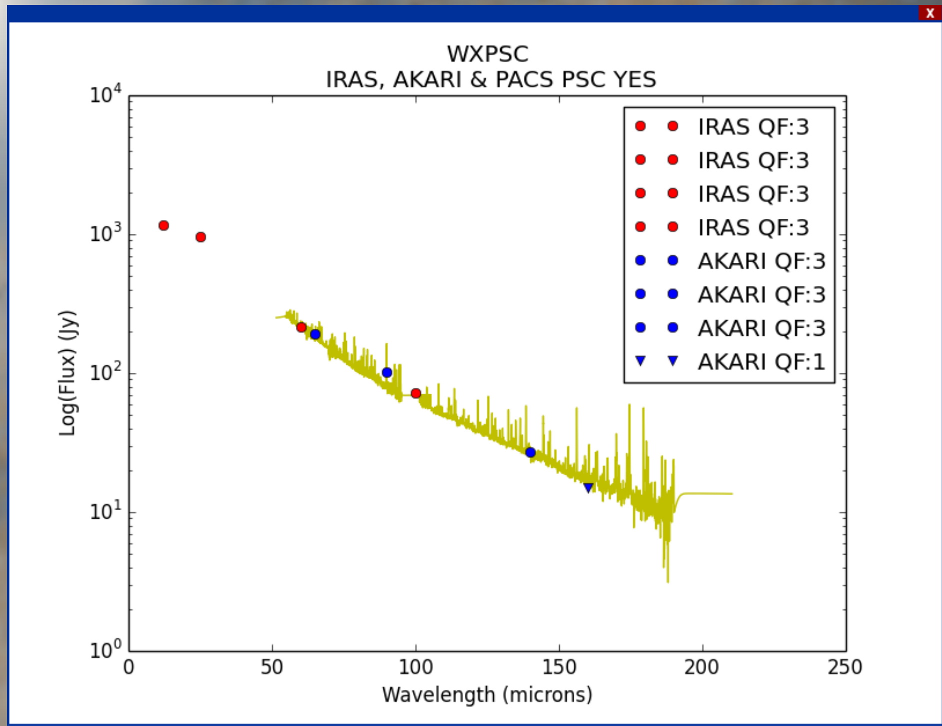
- A catalogue of fully reprocessed, homogenously reduced PACS/SPIRE spectra of all evolved stars observed with Herschel (for PACS: 220 observations, corresponding to 114 individual sources, originally part of 44 different research programmes); SPIRE catalogue is in preparation

- Covering the whole evolutionary stage from the AGB to the PN stage, including some massive red supergiants and LBVs, all chemistries

- Complemented with ancillary data taken by other facilities (IRAS, AKARI photometry, ISO LWS spectroscopy when available)

- PACS spectra are publicly available through a dedicated web interface and soon also through the Herschel Science Archive as a UPDP

  (Ramos-Medina et al. 2017)



THROES: A caTalogue of HeRschel Observations of Evolved Stars

THROES Catalogue

First THROES Catalogue V1.0

Home | Data retrieval | News | Documentation | Help-Desk

RA (?)	DEC (?)	Radius (?)	Search	Reset
0.000 : :	0.000 : :	360.0 : :	all results	default verbosity.

(Maximum Search Radius allowed: 360 degrees)

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Name (?)	
RA (hh:mm:ss) (?)	-
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AOT (?)	%PacsRange%
#Obs (?)	---
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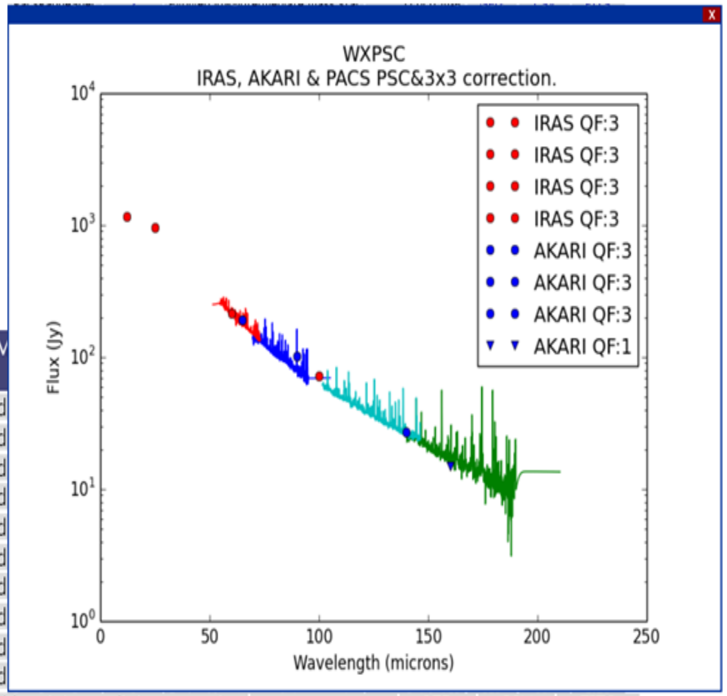
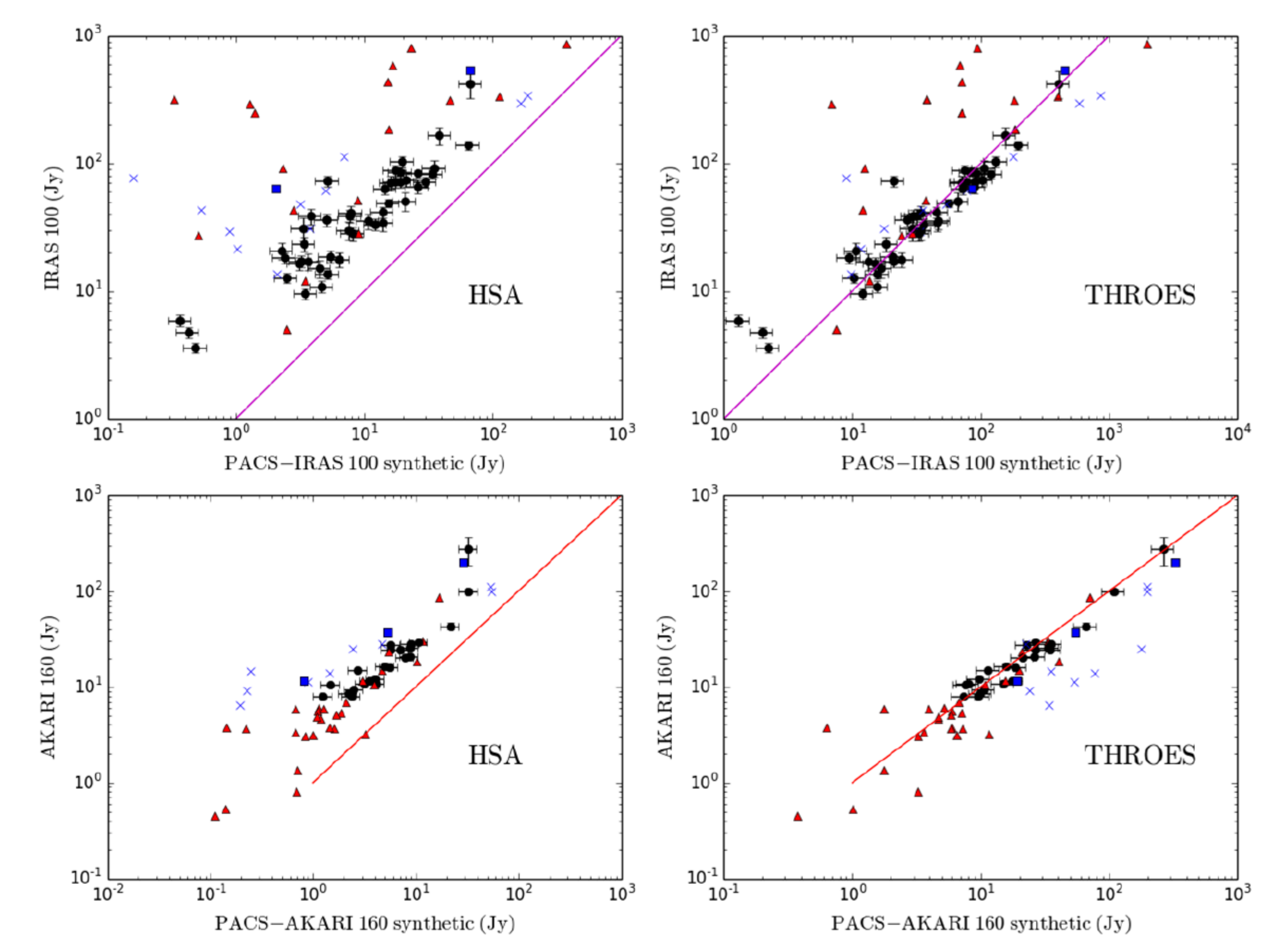
Mass Classification (?)	Evolved low-intermediate mass star

135 data found.

RA (ICRS) (deg)	DEC (ICRS) (deg)	RA (ICRS) (hh:mm:ss)	DEC (ICRS) (dd:mm:ss)	Name (?)	AOT (?)	#Obs (?)	M				
3.2542	72.5219	0:13:01.010	72:31:19.10	NGC_40	PacsLineSpec/PacsRangeSpec	4	Evolved				
16.1897	79.4461	1:04:45.540	79:26:46.30	IRAS_01005+7910	PacsRangeSpec	2	Evolved				
16.6082	12.598	1:06:25.980	12:35:53.00	WX_PSC	PacsRangeSpec	2	Evolved				
34.8366	-2.9776	2:19:20.790	-2:58:39.50	OMI_CET	PacsRangeSpec	2	Evolved				
51.6229	47.5301	3:26:29.510	47:31:48.60	V384_Per	PacsLineSpec/PacsRangeSpec	3	Evolved				
58.3701	11.4062	3:53:28.840	11:24:22.60	NML_TAU	PacsRangeSpec	3	Evolved				
69.1899	-62.0771	4:36:45.590	-62:04:37.80	R_DOR	PacsRangeSpec	2	Evolved				
70.7236	36.1147	4:42:53.670	36:06:53.20	AFGL_618	PacsRangeSpec	3	Evolved				
74.9014	-14.8062	4:59:36.350	-14:48:22.50	R_Lep	PacsLineSpec/PacsRangeSpec	3	Evolved				
75.2099	56.1812	5:00:50.390	56:10:52.60	TX_CAM	PacsRangeSpec	2	Evolved				
75.5307	-71.3369	5:02:07.390	-71:20:13.10	HDE_269006	PacsRangeSpec	1	Evolved low-intermediate mass star	-	SED	CSV	FITS
76.3488	1.1776	5:05:23.720	1:10:39.50	W_Ori	PacsLineSpec/PacsRangeSpec	3	Evolved low-intermediate mass star	C rich AGB	SED	CSV	FITS
77.831	52.8758	5:11:19.440	52:52:33.20	IRC+50137	PacsRangeSpec	1	Evolved low-intermediate mass star	OH/IR star	SED	CSV	FITS
81.781	34.1496	5:27:07.450	34:08:58.60	S_Aur	PacsLineSpec/PacsRangeSpec	3	Evolved low-intermediate mass star	C rich AGB	SED	CSV	FITS

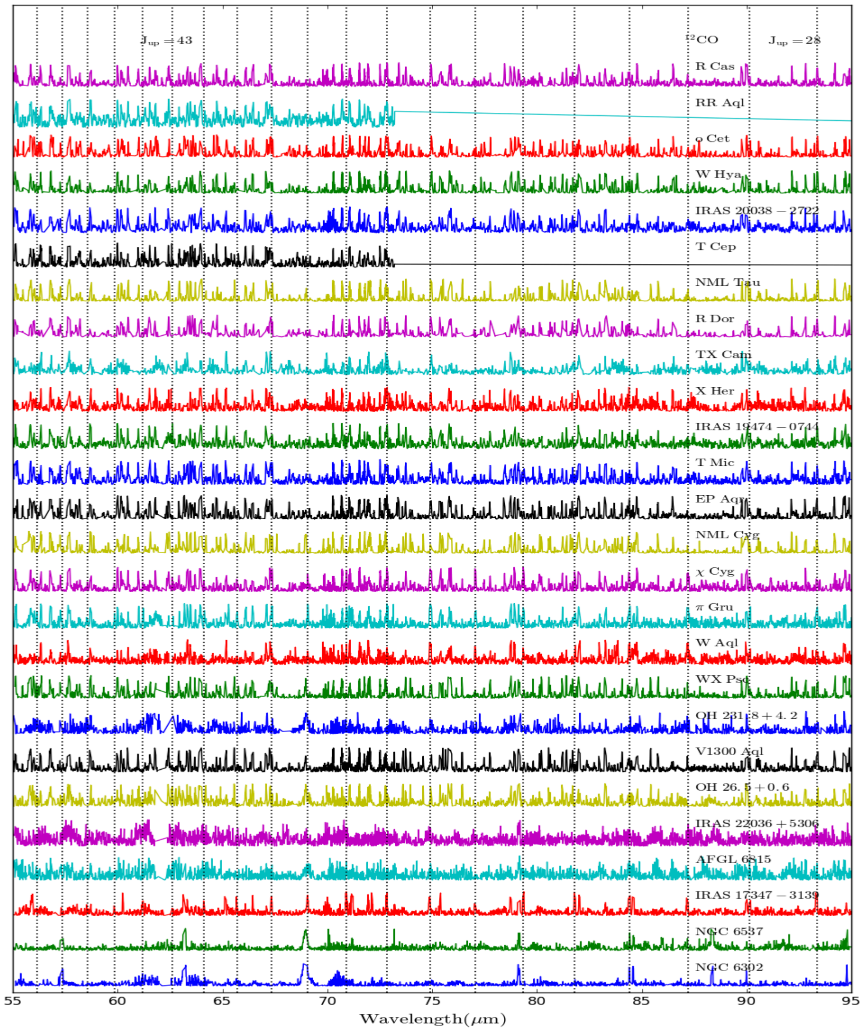


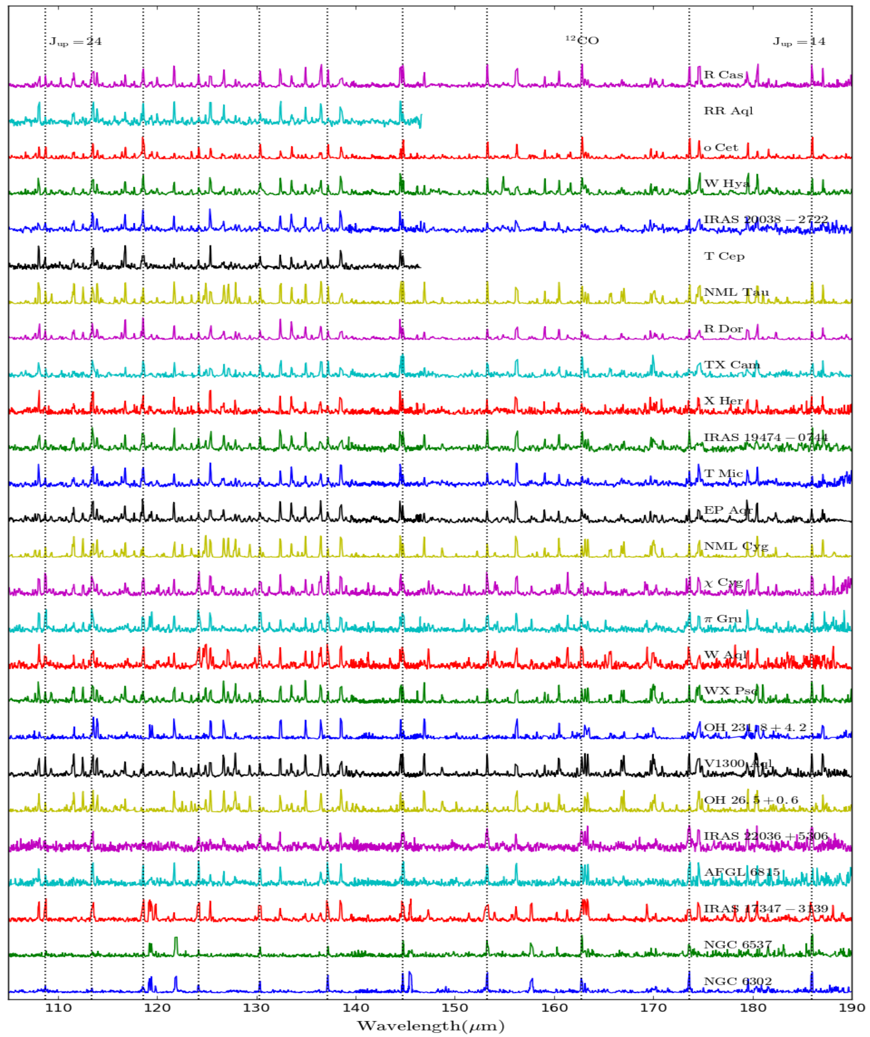
THROES: a science-ready library of interactively reduced Herschel spectra



THROES: a science-ready library of interactively reduced Herschel spectra

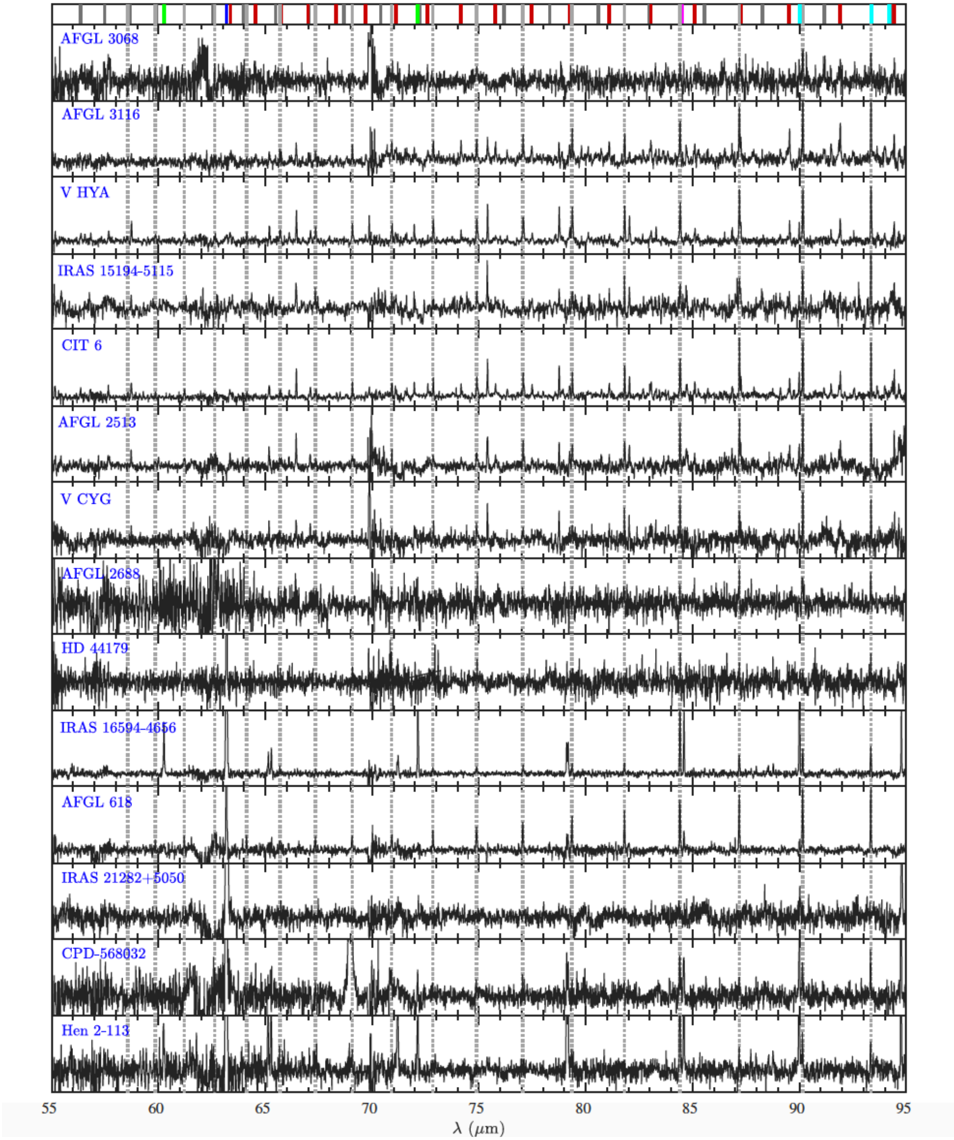
O-rich molecular line sources

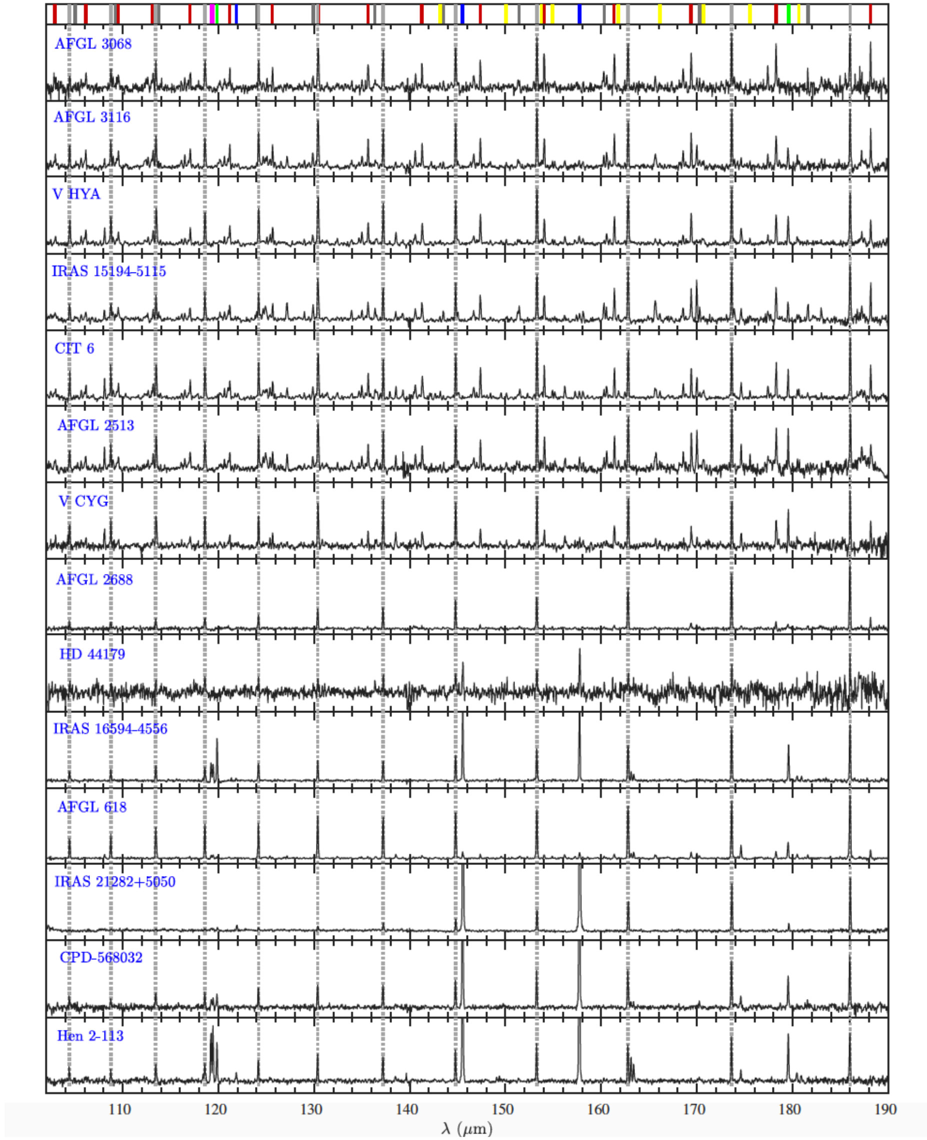




THROES: a science-ready library of interactively reduced Herschel spectra

C-rich molecular line sources

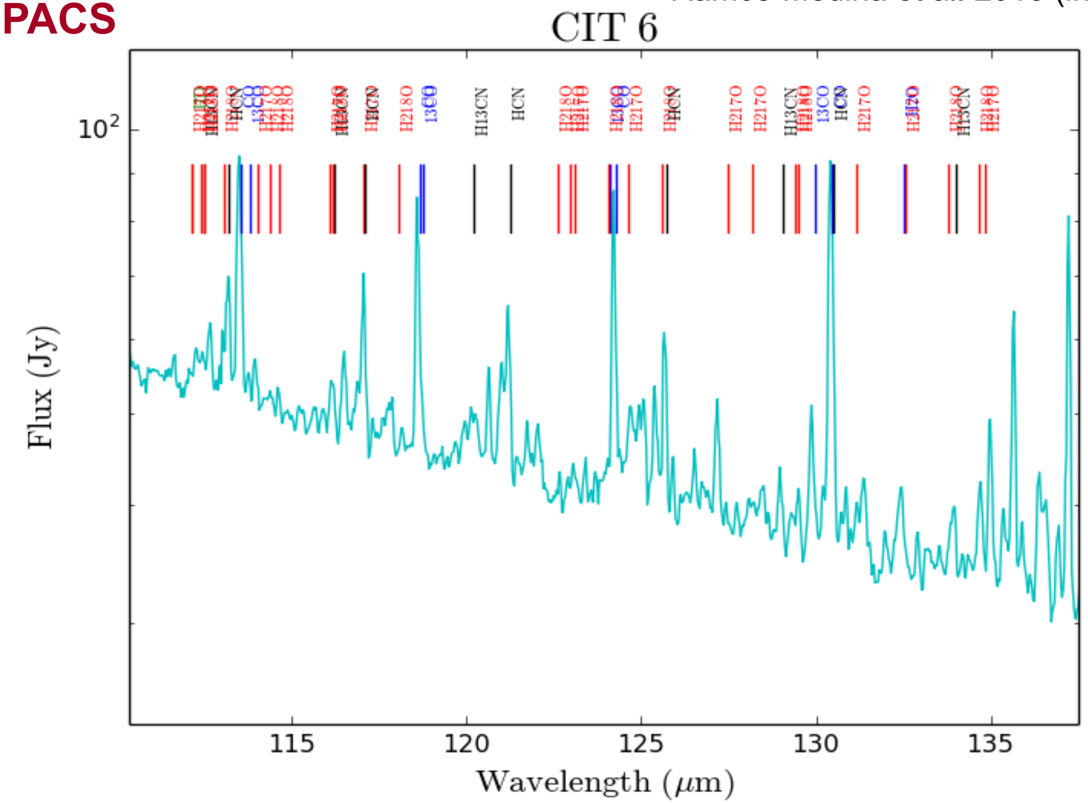




Spectral feature catalogues under construction (PACS/SPIRE)

PACS

Ramos-Medina et al. 2018 (in prep.)



Hopwood et al. 2017 (in prep.)

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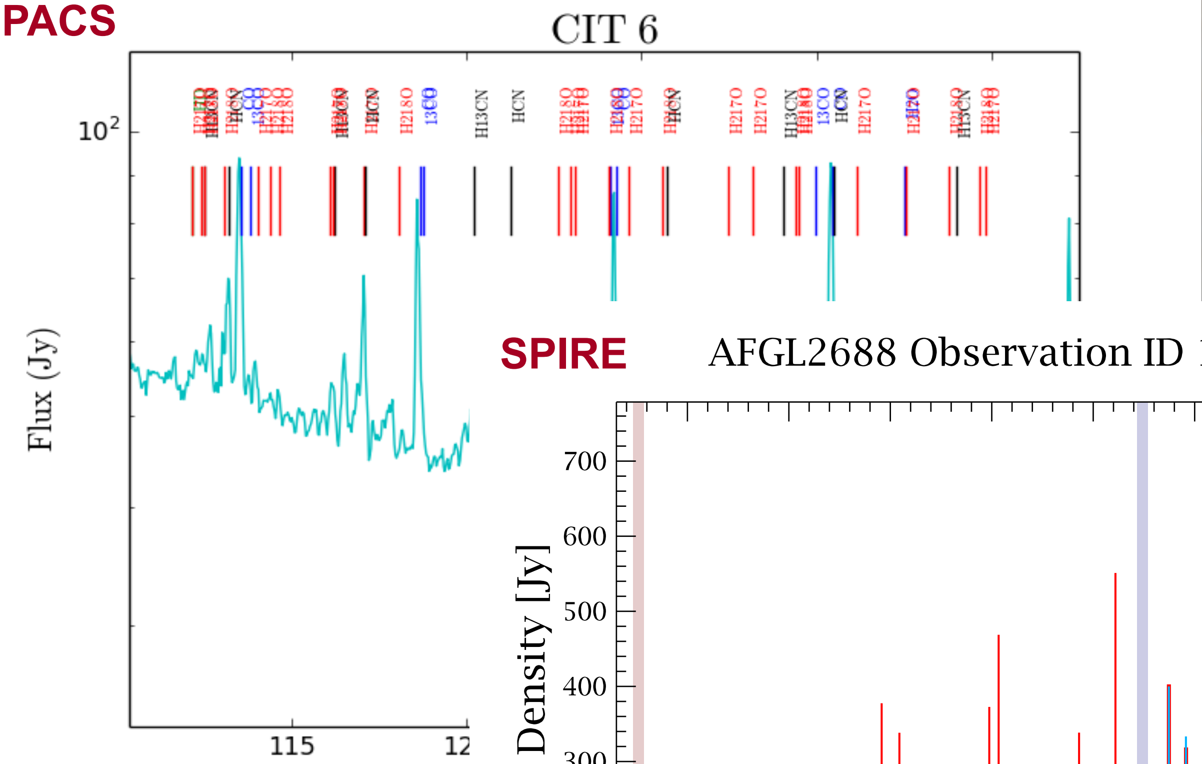
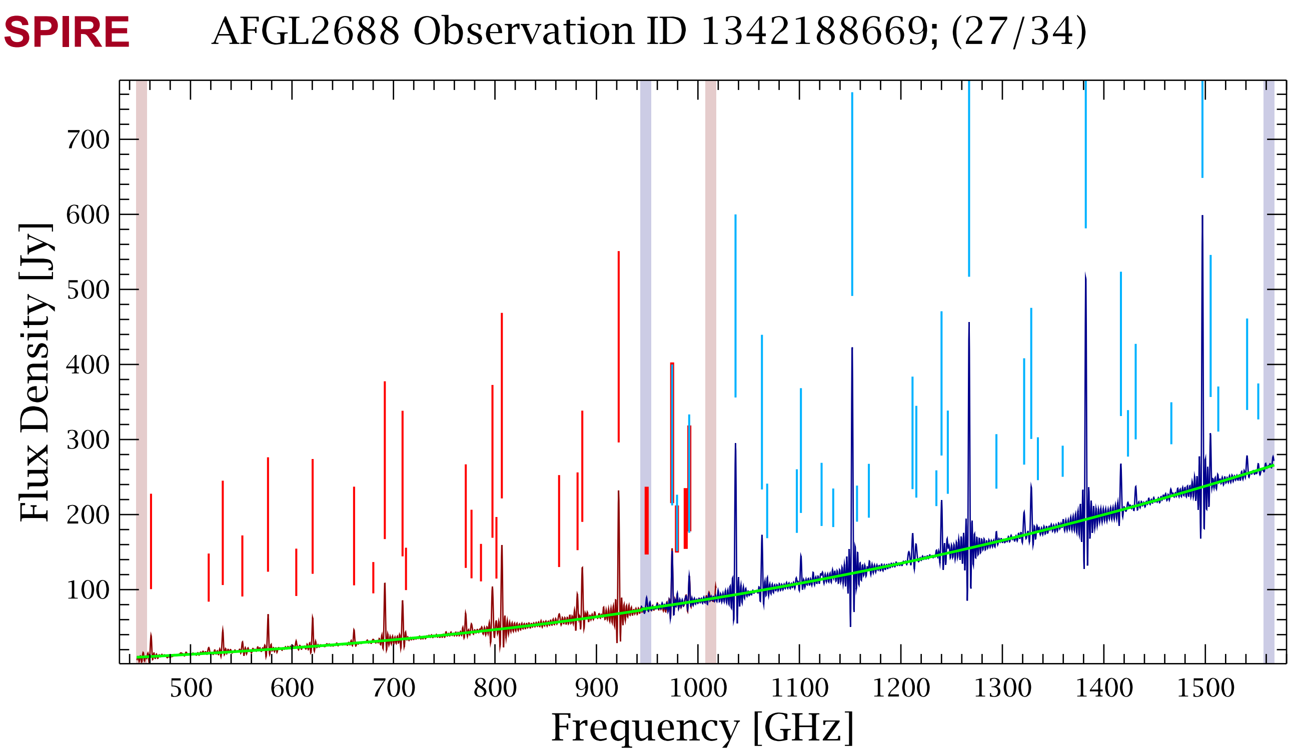


SPIRE



Hopwood et al. 2017 (in prep.)

Molecules in O-rich AGB stars

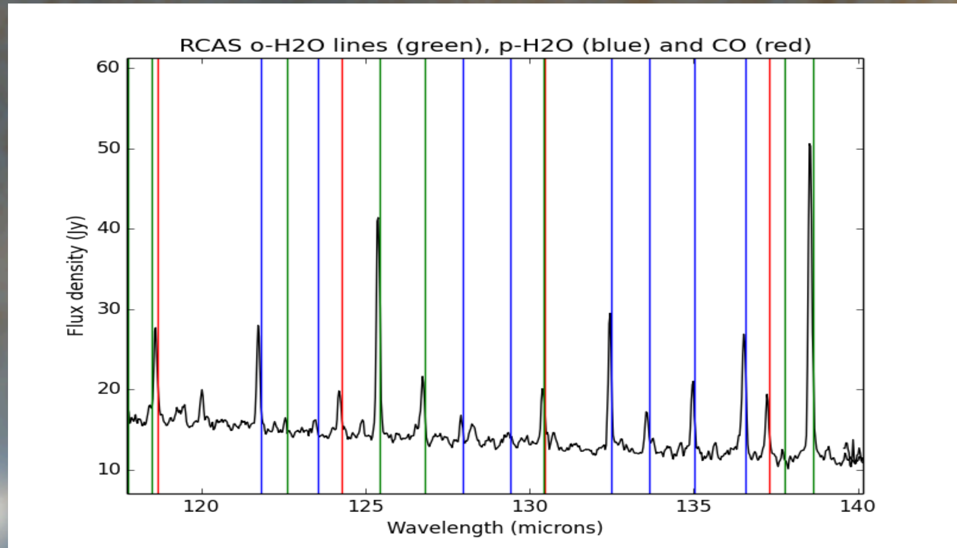
- Most O-rich AGB stars observed display high-J CO lines + many ortho- and para- lines of warm water vapour

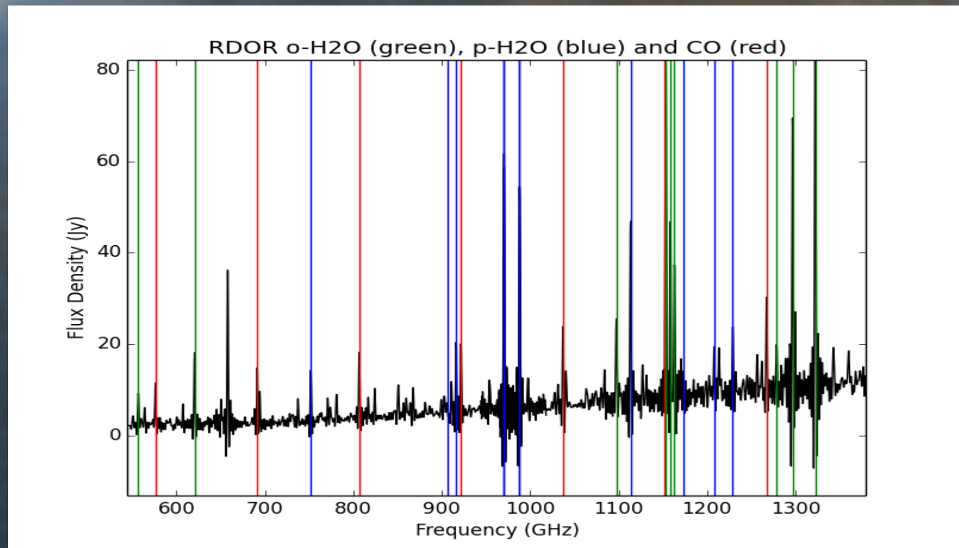
- Indications of shock chemistry induced by stellar pulsation

- Rotational diagrams of CO and H_2O sometimes cannot be fit with one single temperature component

- Different lines form at different regions of the envelope

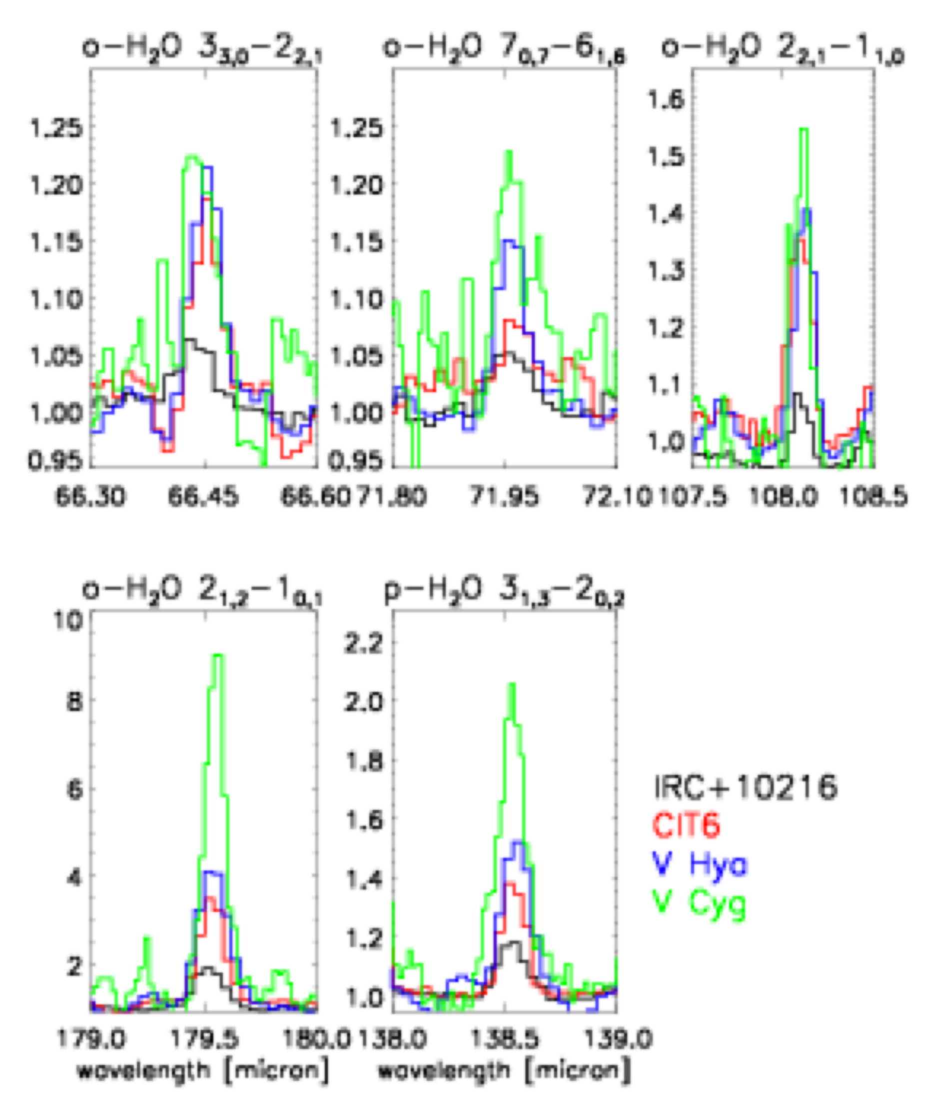
- Surprisingly, many similarities with C-rich AGB stars!





Molecules in C-rich AGB stars

- Detection of warm water vapour also in C-rich AGB stars
- Produced via photochemical processes in the outer envelope or in the inner regions if the shell is clumpy enough (Decin et al. 2010)
- Alternative scenario: an out-of-equilibrium shock chemistry in the inner regions of the circumstellar shell (Cherchneff 2011)
- Water vapour is now detected in ALL ~~(but one)~~ C-rich stars observed by Herschel
- Abundances anticorrelated with mass loss rate (Lombaert et al. 2016)



PACS/SPIRE CO rotational diagrams

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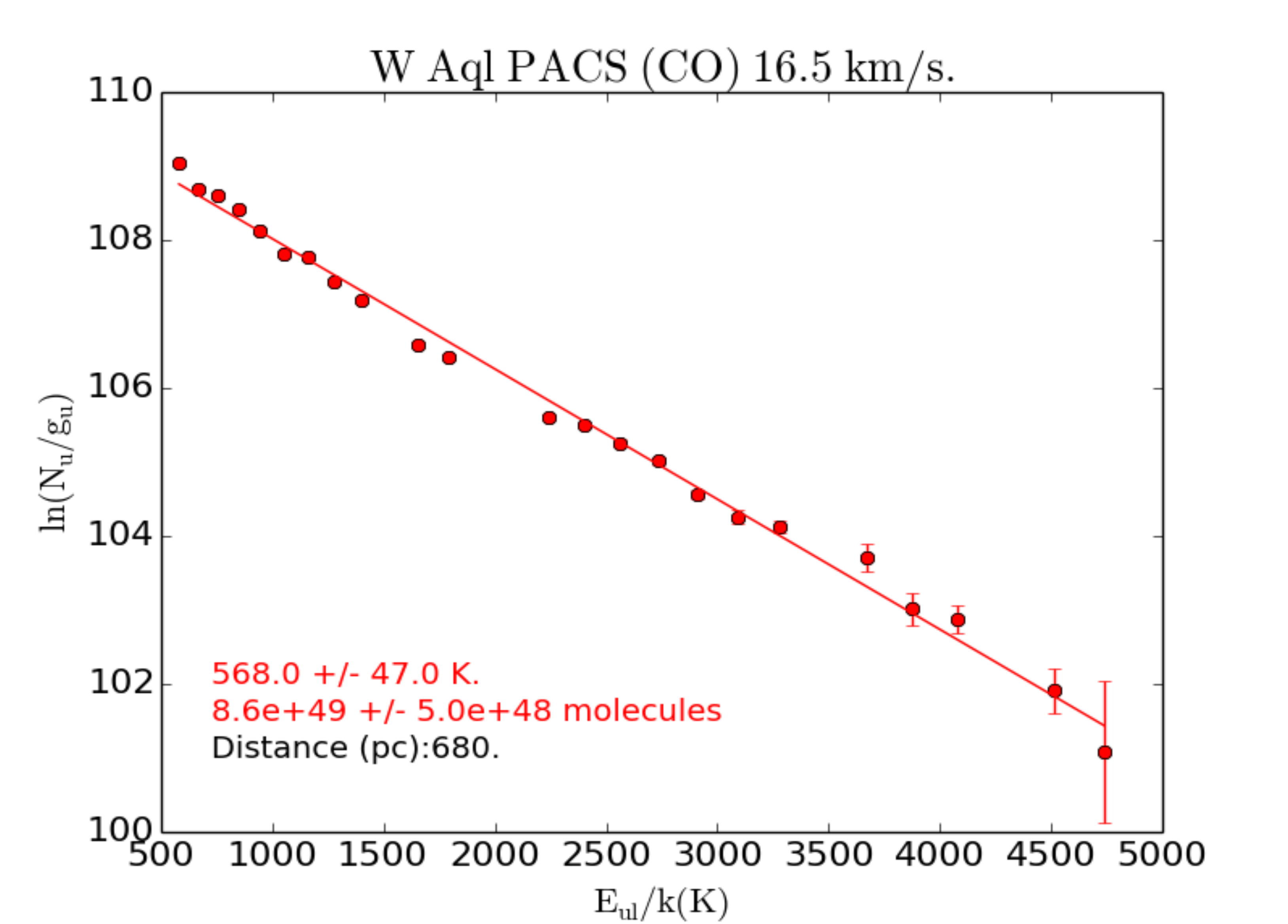

PACS/SPIRE CO rotational diagrams

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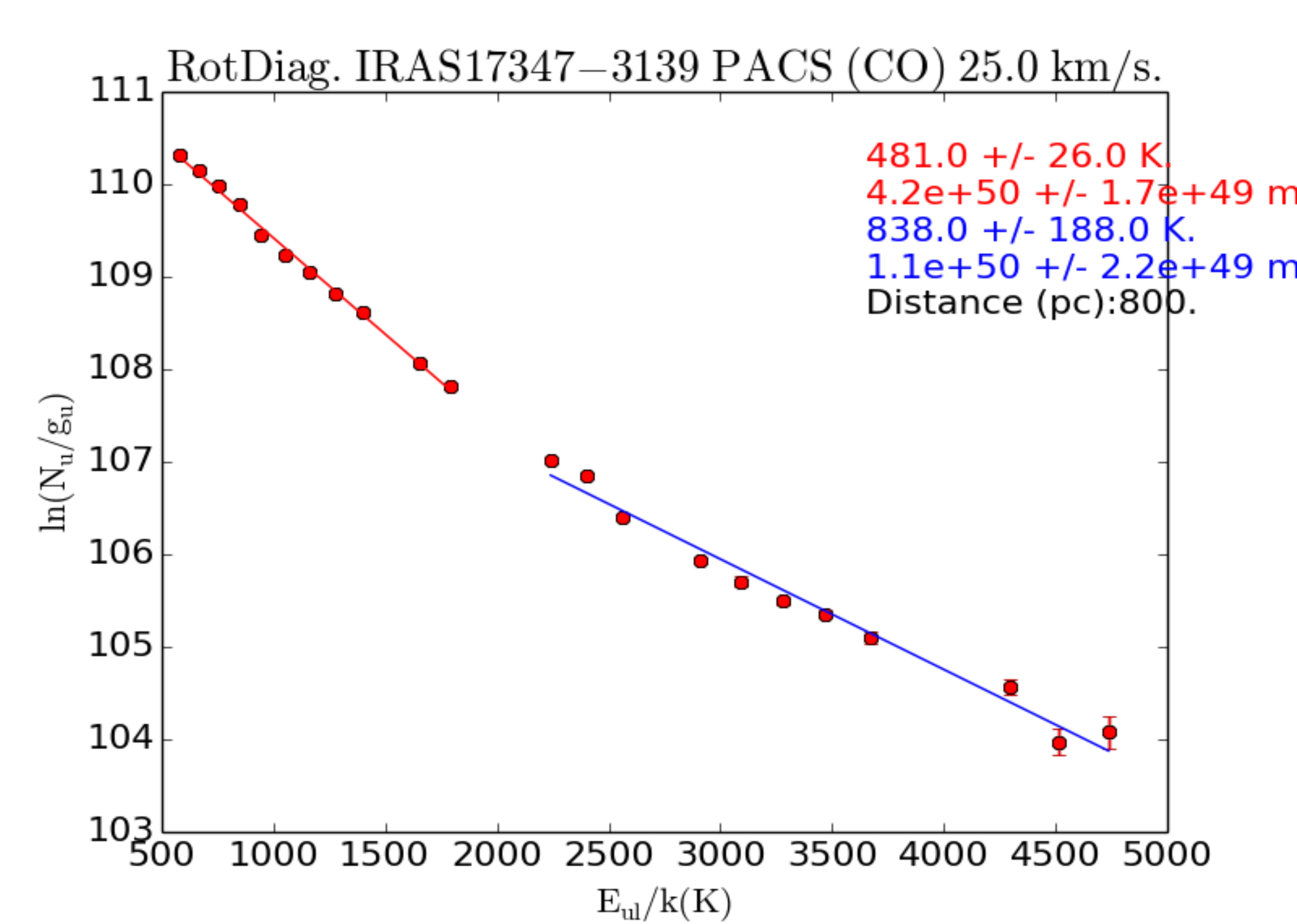

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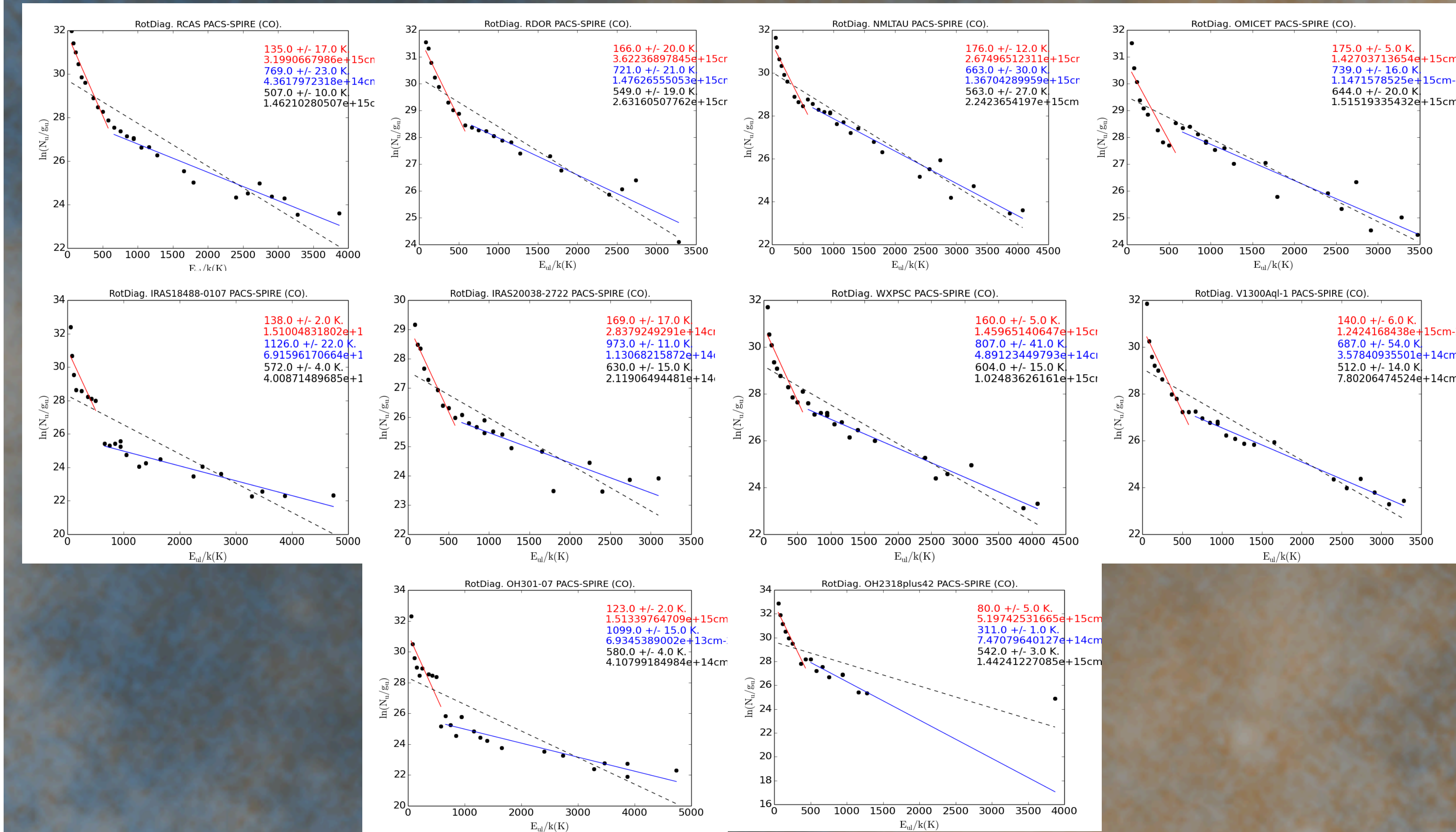

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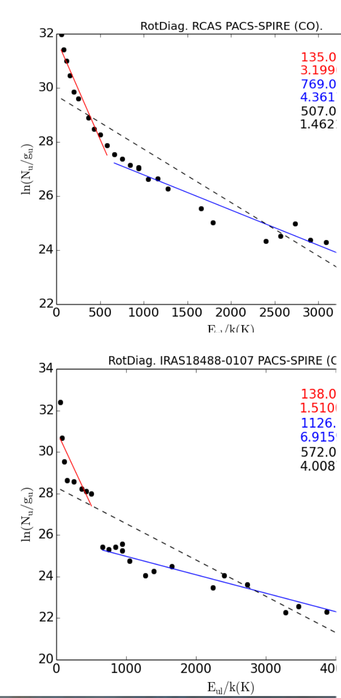
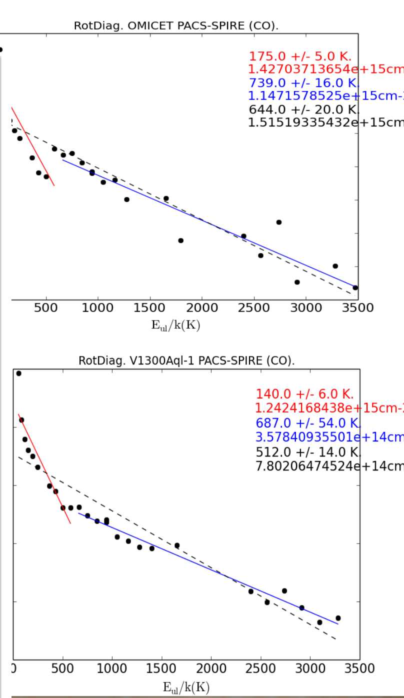
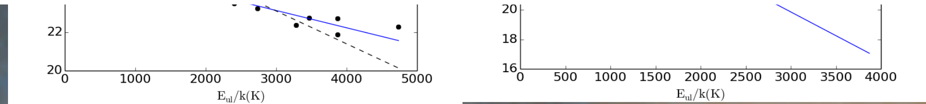


Target name	Trot(K)	N(cm-2)
RCAS	135 / 769	3.20e15 / 4.36e14
RDOR	166 / 721	3.62e15 / 1.48e15
NML TAU	176 / 663	2.67e15 / 1.37e15
OMI CET	175 / 739	1.43e15 / 1.15e15
IRAS 18488-0107	138 1126	1.51e15 / 6.92e13
IRAS 20038-2722	169 / 973	2.84e14 / 1.13e14
WX PSC	160 / 807	1.46e15 / 4.89e14
V1300 Aql	140 / 687	1.24e15 / 3.58e14
OH 30.1-0.7	123 / 1099	1.51e15 / 6.93e13
OH 231.8+4.2	80 / 311	5.20e15 / 7.47e14

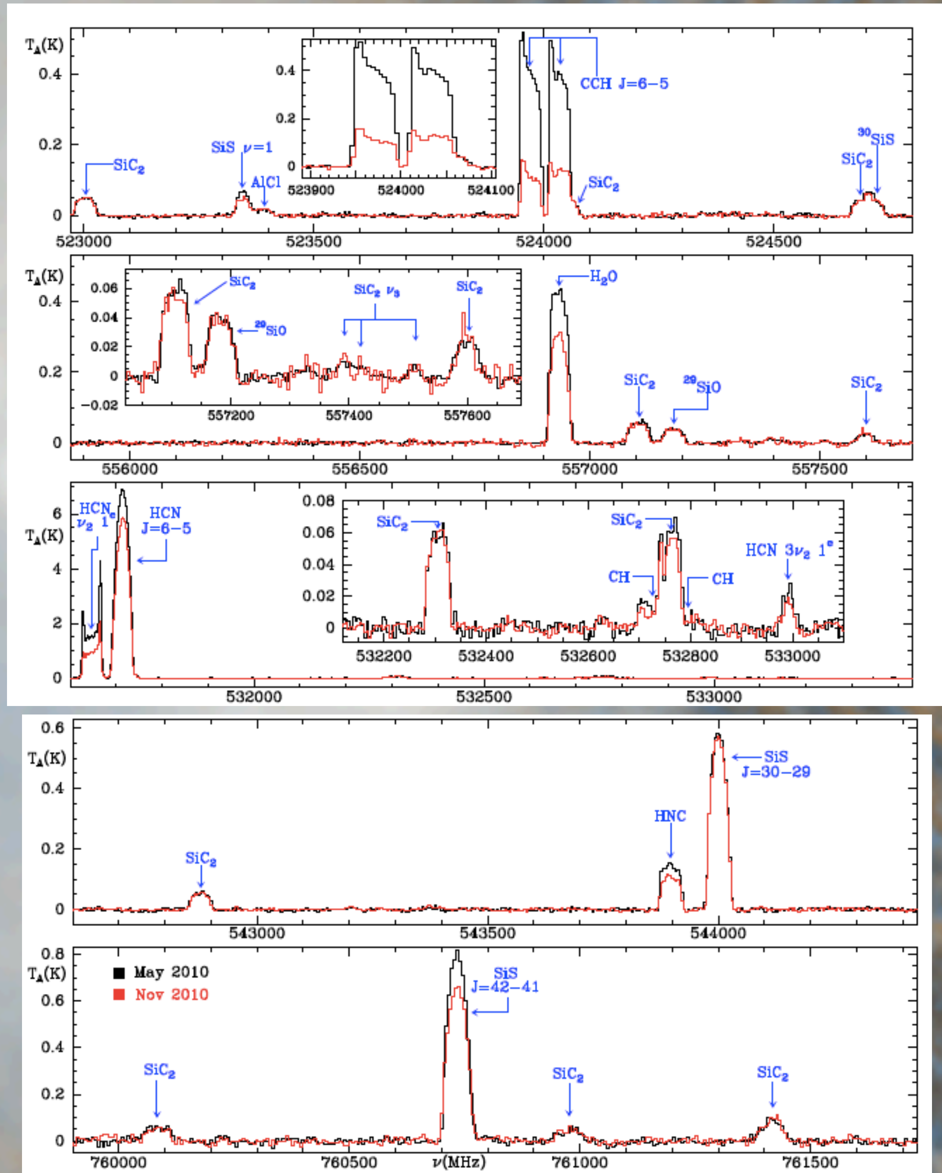




Other spectroscopic results (HIFI)

- Detection of time variability in the intensity of (some) molecular lines in IRC+10216 driven by infrared pumping rates (Cernicharo et al. 2014)

- Confirmed with IRAM 30m data, monitoring program ongoing for 3 years now (2 pulsation cycles)



Other spectroscopic results (HIFI)

- HIFI observations of the high rotational CO transitions + ground based CO and observations of different water molecule isotopes in extreme OH/IR stars

- Low $^{18}O/^{17}O$ and $^{12}C/^{13}C$ ratios confirm that these objects have undergone HBB and hence they are the result of the evolution of massive stars ($M > 5\ M_{\odot}$)

  (Justtanont et al. 2013)

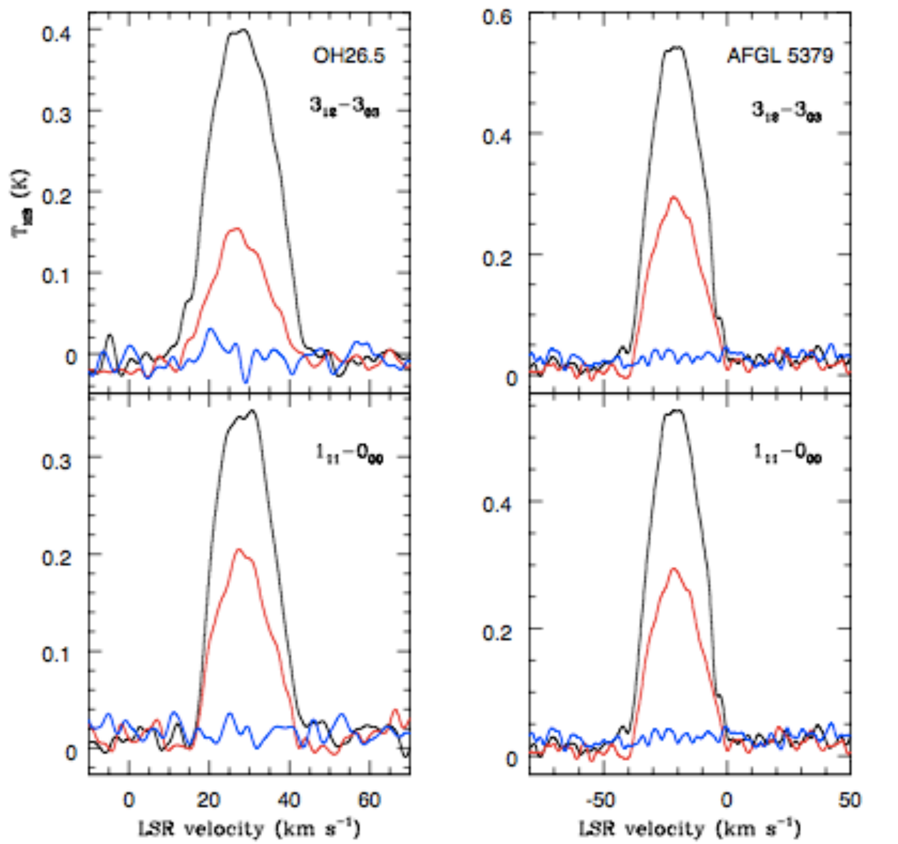
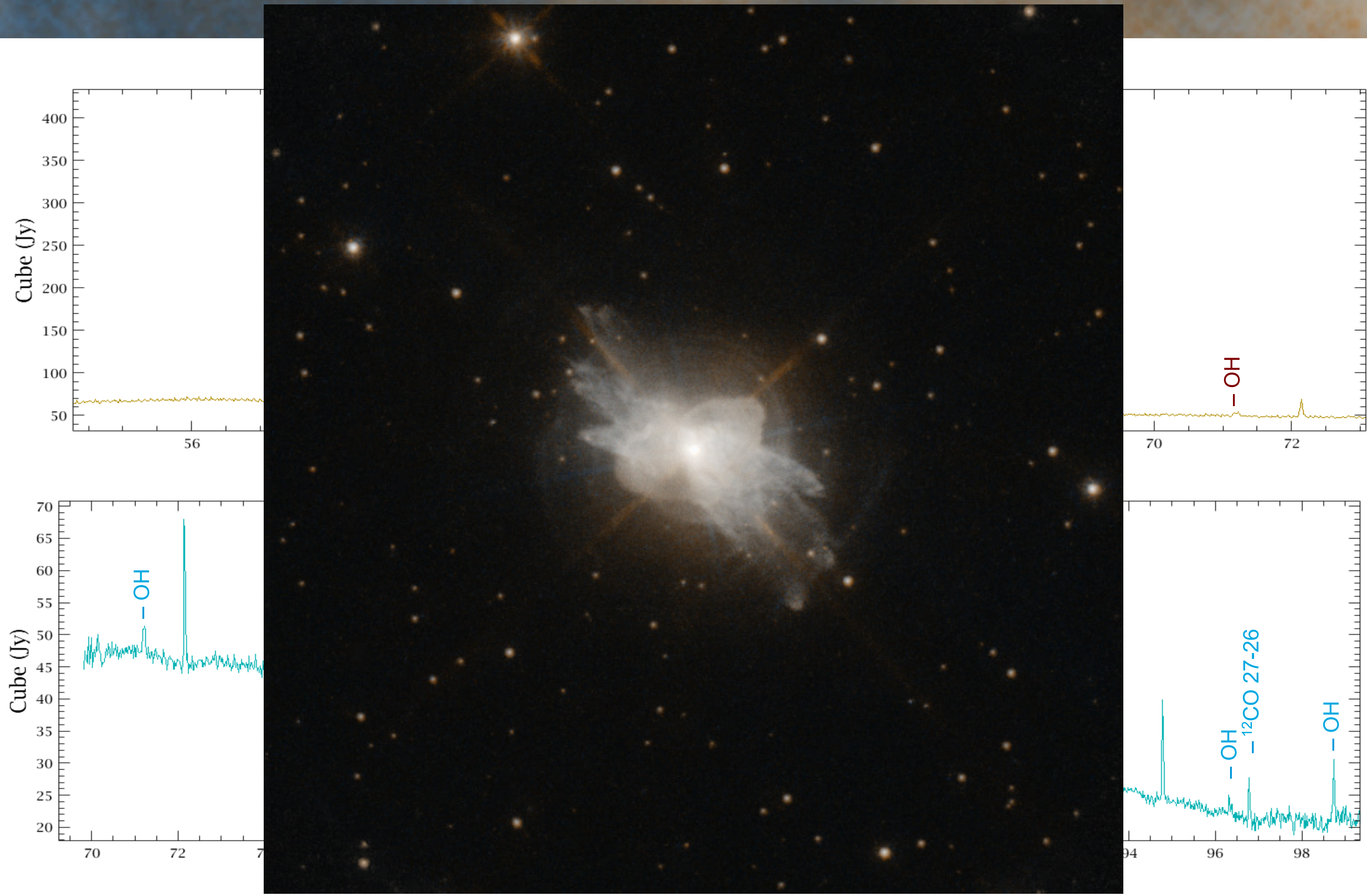


Fig. 11. HIFISTARS spectra of OH 26.5+0.6 (left) and AFGL 5379 (right) showing the transitions $3_{12}-3_{03}$ and $1_{11}-0_{00}$ of $H_2^{16}O$ (black), $H_2^{17}O$ (red) and $H_2^{18}O$ (blue). The $H_2^{18}O$ lines are not detected in either source in both ortho- and para-H_2O.

Molecular lines in post-AGB stars (IRAS 16594-4656)



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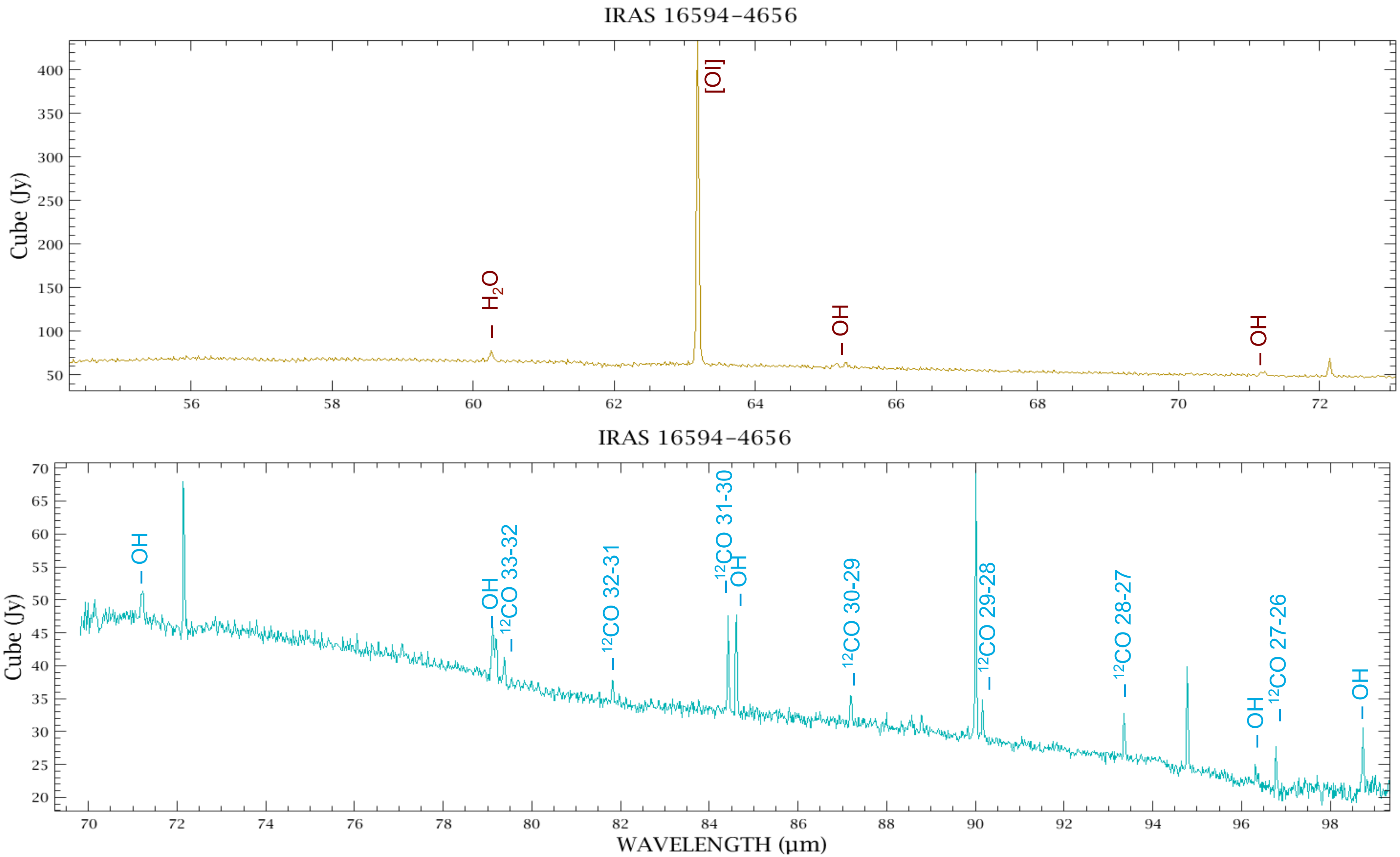

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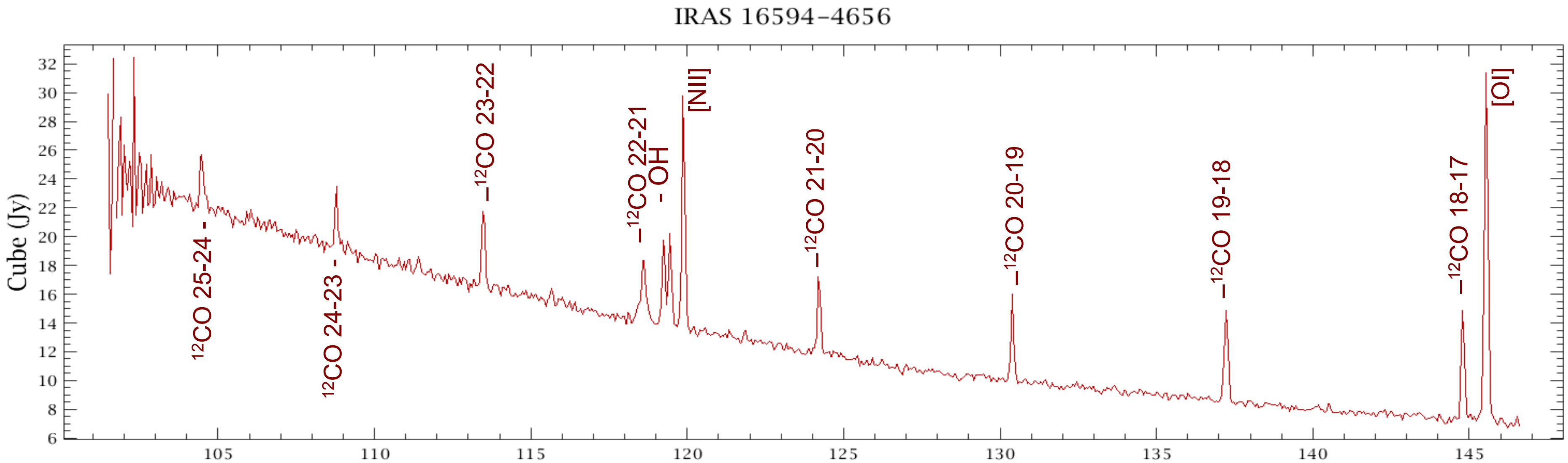
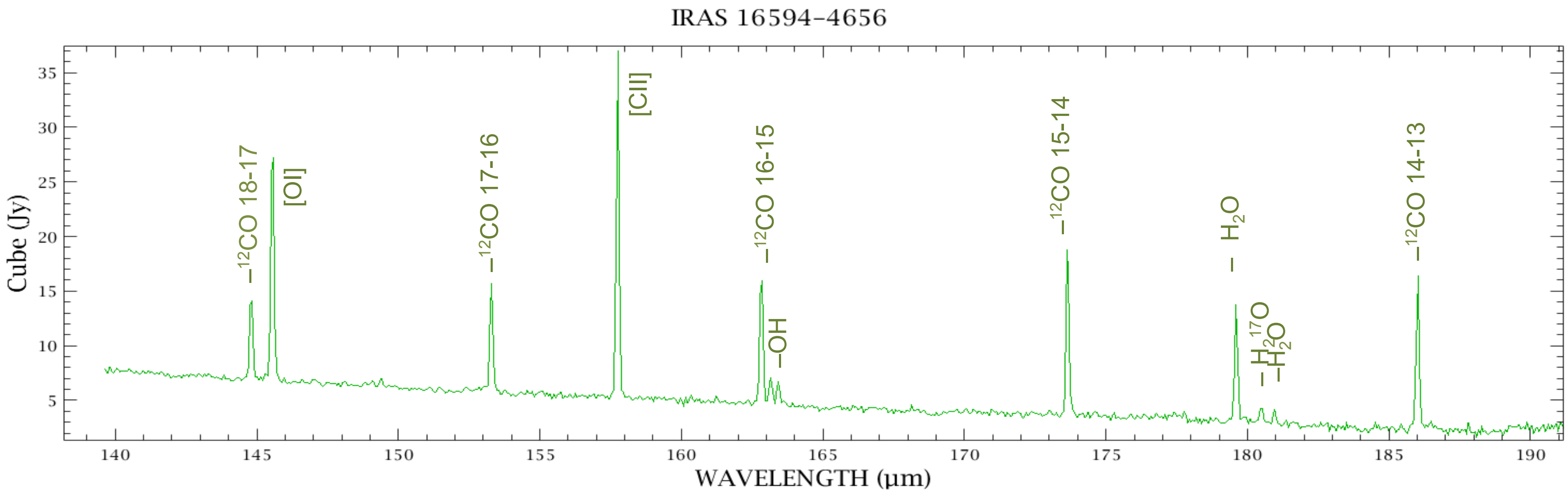
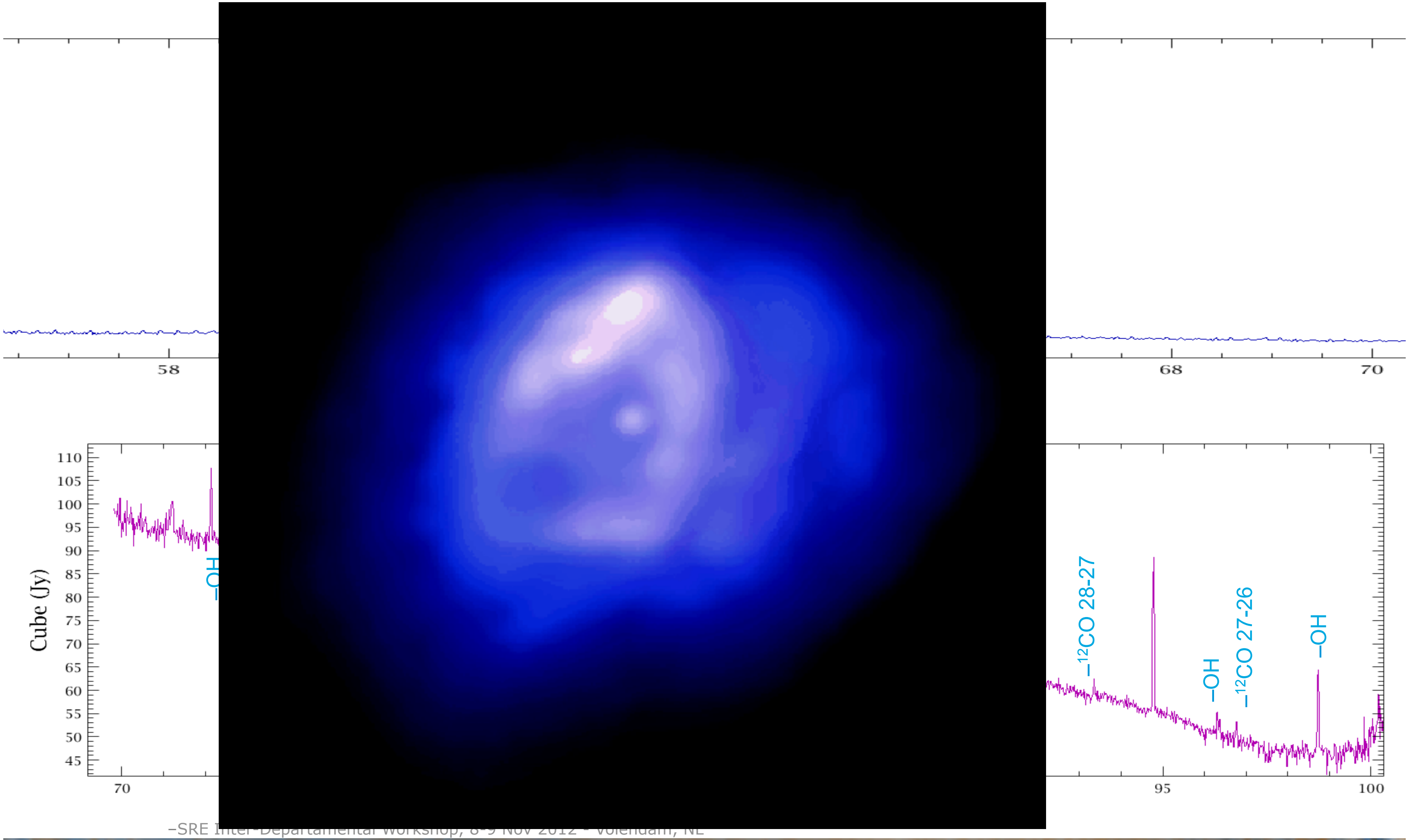




Molecular lines in young PNe (Hen 2-113)



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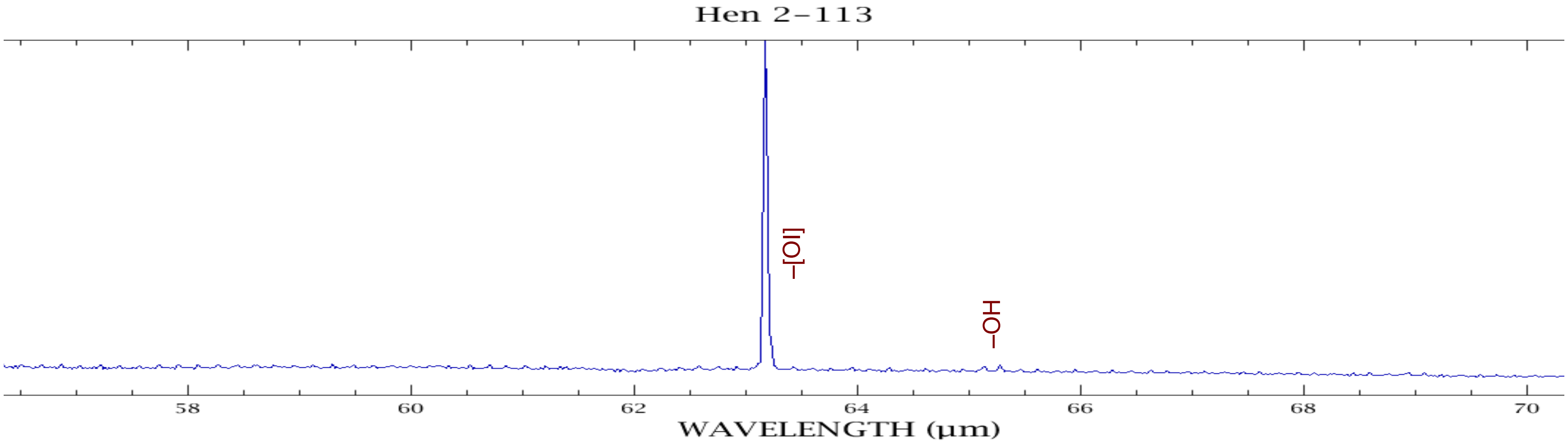
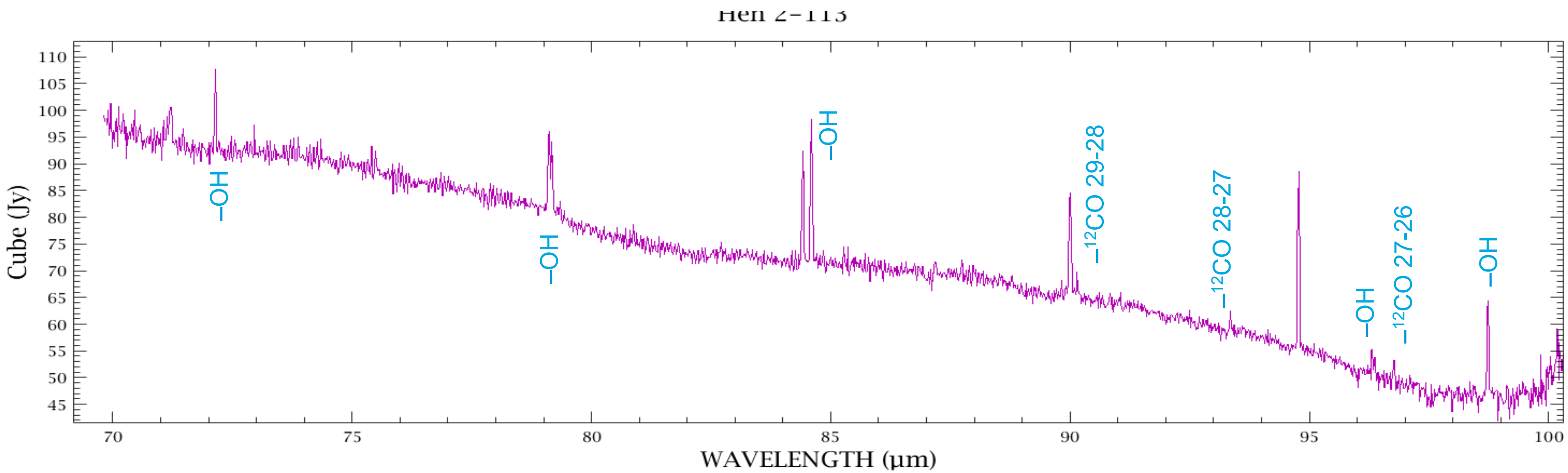
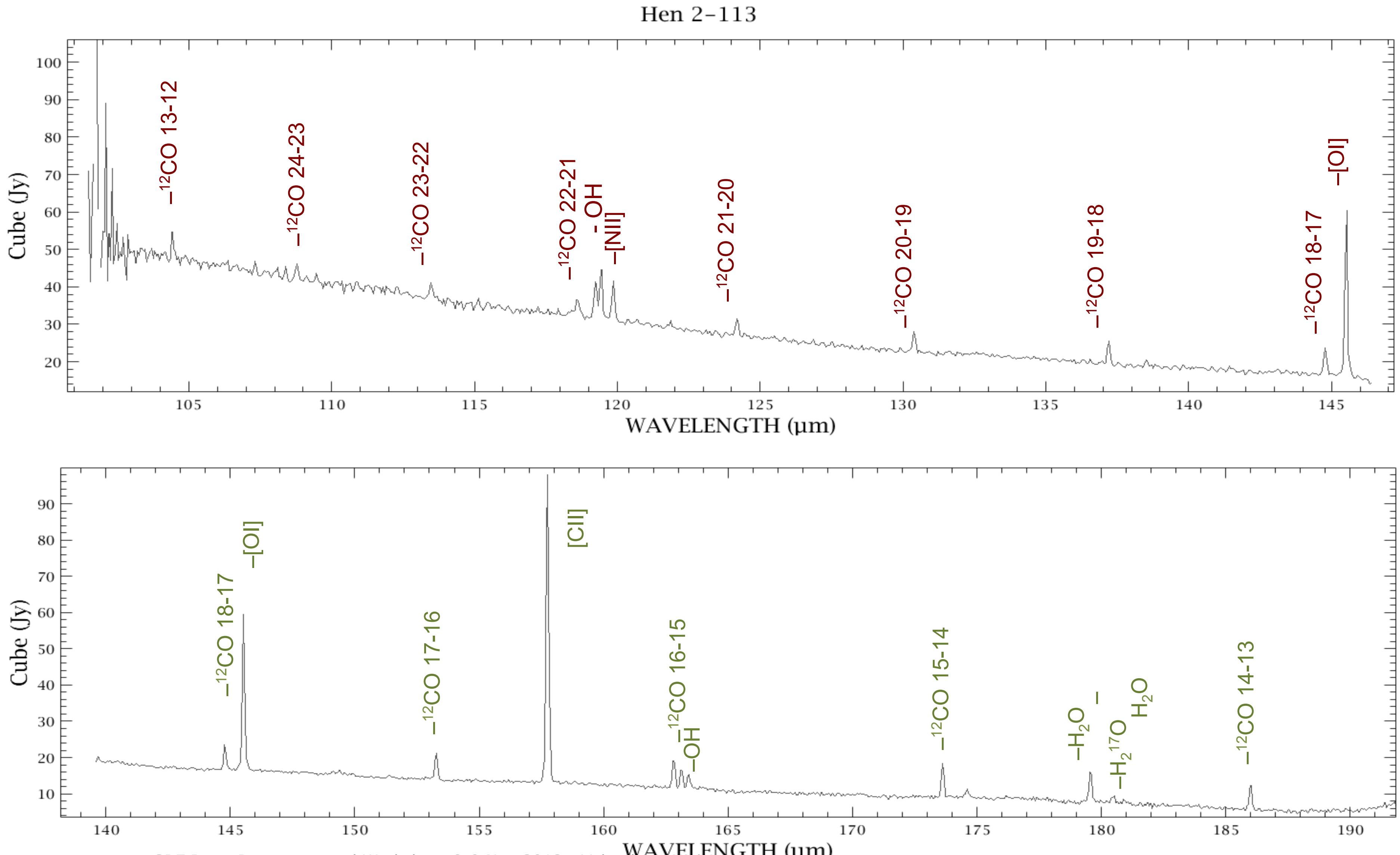




Molecular lines in young PNe (Hen 2-113)



Summary

Summary

- Low- and intermediate-mass evolved stars are ideal test beds for molecular astrophysics – unique opportunity to study some processes that only take place in the circumstellar envelopes of these stars

- Different initial conditions depending on nucleosynthesis history (C-rich versus O-rich chemistry); rapidly changing environment – impact of stellar pulsation – impressive molecular richness of some sources

- The detection of a large number of water vapour emission lines in the Herschel spectra of both C-rich and O-rich evolved AGB stars can be explained if the water is formed in the warm inner regions of their envelopes. The high-J rotational CO lines detected in these sources seem to trace the same inner regions of the circumstellar envelope. Indications of out-of-equilibrium shock chemistry

- Shock chemistry might also be induced by episodic mass loss and outflows in post-AGB stars and young PNe

- The analysis of a large sample of evolved stars with THROES may provide the wide picture missing if we restrict our analysis to only a few individual sources. The data is ready for you to use!!


THANK YOU!